Characterization of laser-assisted and laser-driven EUV sources for metrology applications

Yusuke Teramoto, Bárbara Santos, Guido Mertens, Margarete Kops, Ralf Kops
BLV Licht- und Vakuumtechnik GmbH (Germany)

Alexander von Wezyk, Klaus Bergmann
Fraunhofer ILT (Germany)

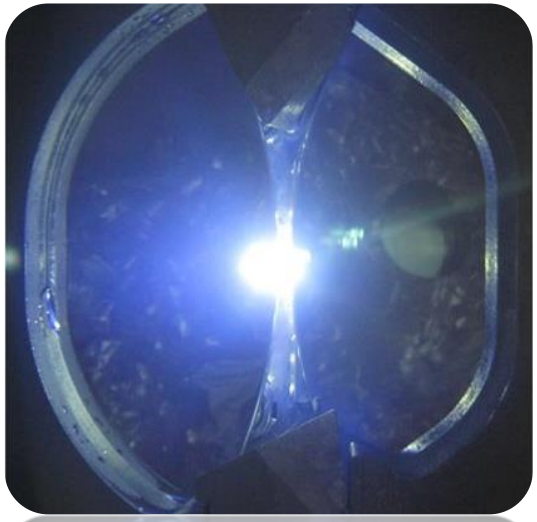
Hironobu Yabuta, Akihisa Nagano, Takahiro Shirai, Kunihiko Kasama
Ushio Inc. (Japan)

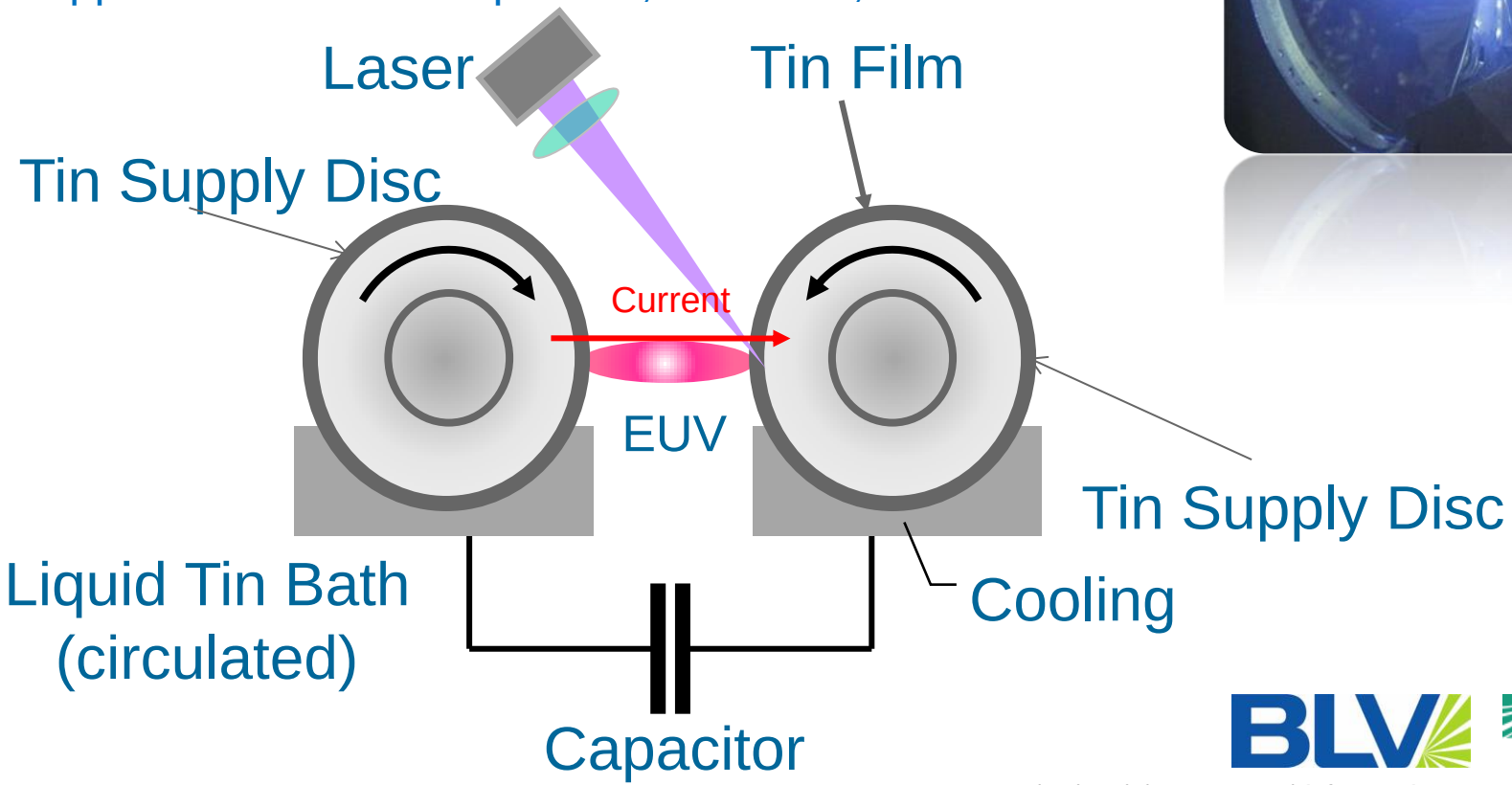
OUTLINE

- **LDP source basic principle and performance**
- **LDP source brightness and stability**
- **Compact source basic principle**
- **Compact source brightness and stability**
- **Summary**

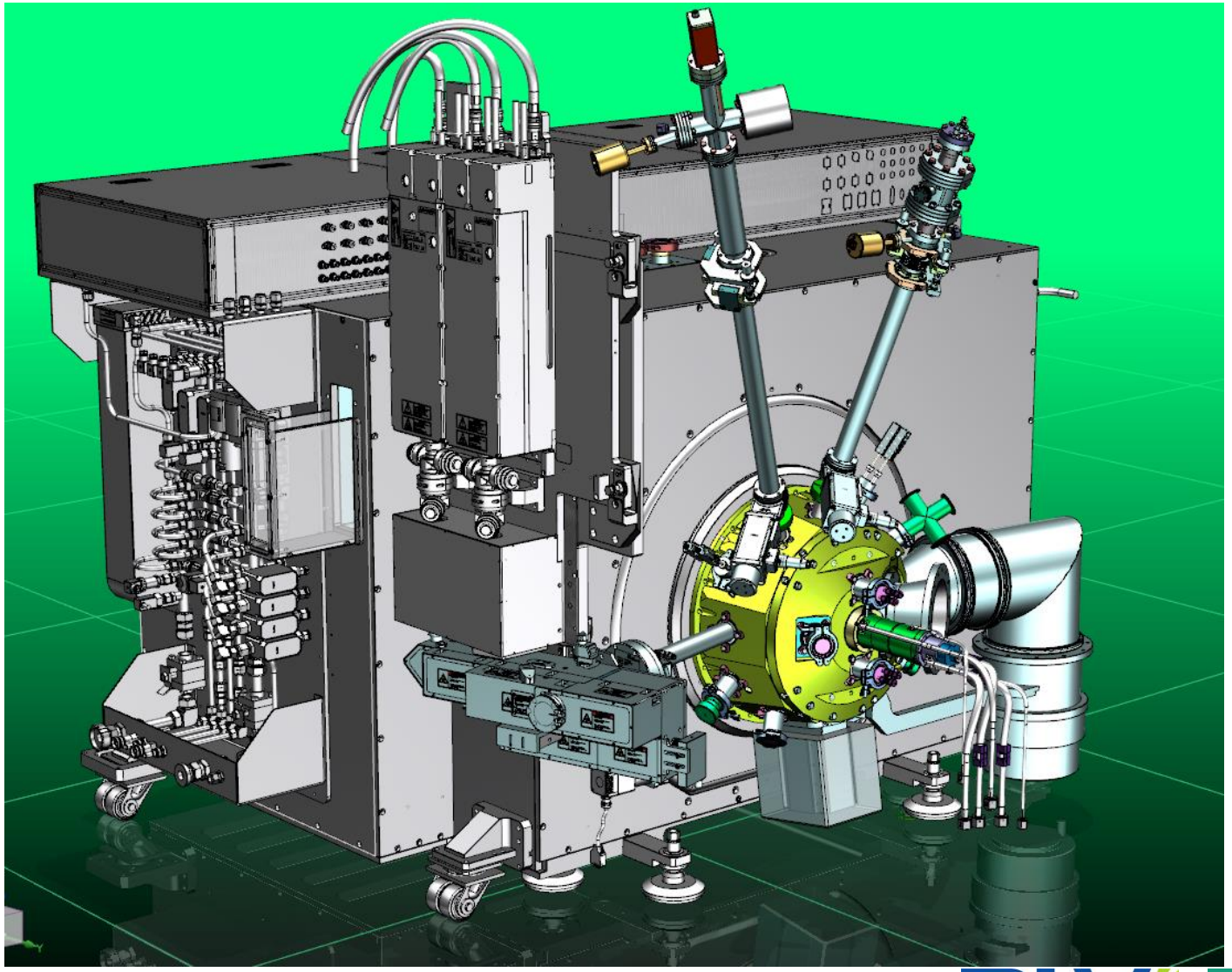
Laser-assisted Discharge-produced Plasma

- Wavelength: 13.5 nm
- High brightness
- Appropriate plasma size (broad profile)
- Stable: no spatial and timing synchronization needed
- Reliable: 24/7 operation
- Clean: powerful debris shield
- Applications: mask inspection, beamline, etc



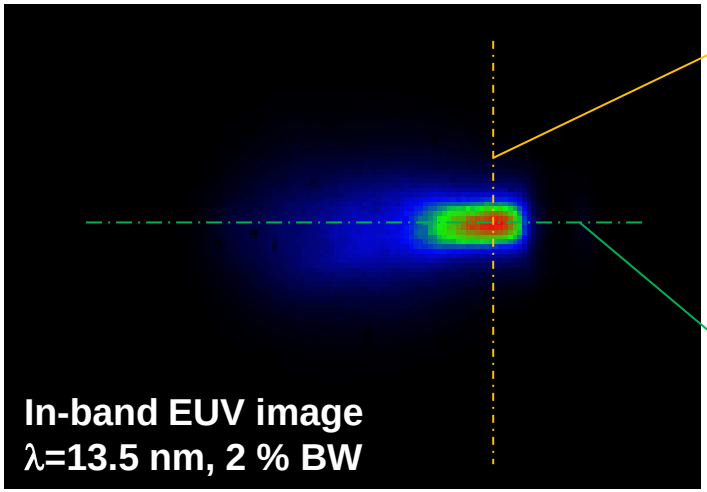


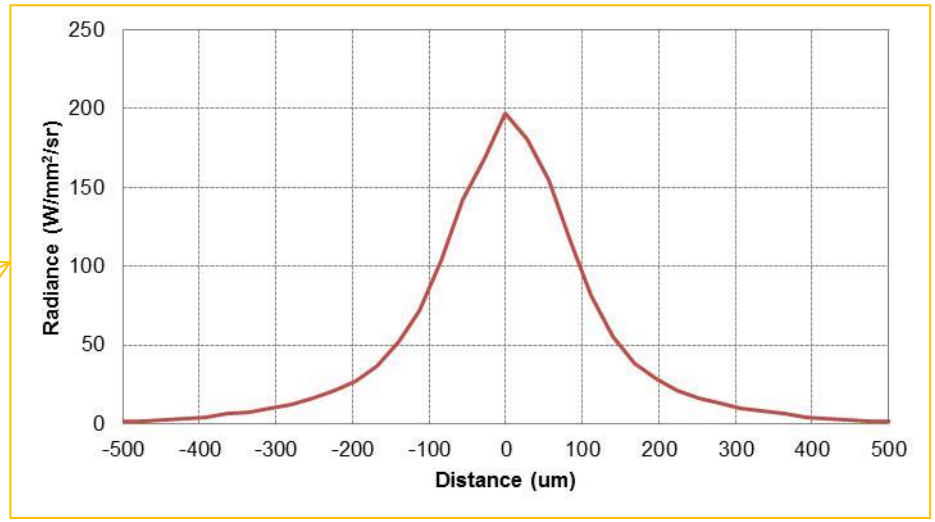
LDP machine architecture



High brightness, appropriate plasma size

- High peak brightness
- Plasma size smaller than DPP, larger than LPP: good spatial stability





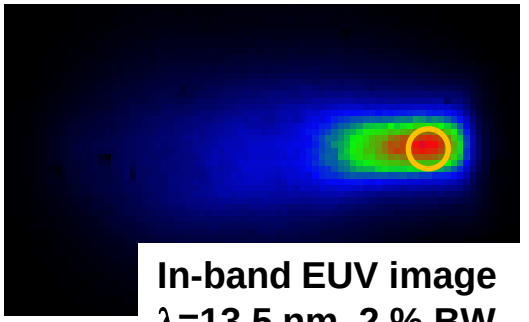
10 kHz, continuous operation

- Diameter: 200 μm (FWHM)
- Length: 450 μm (FWHM)

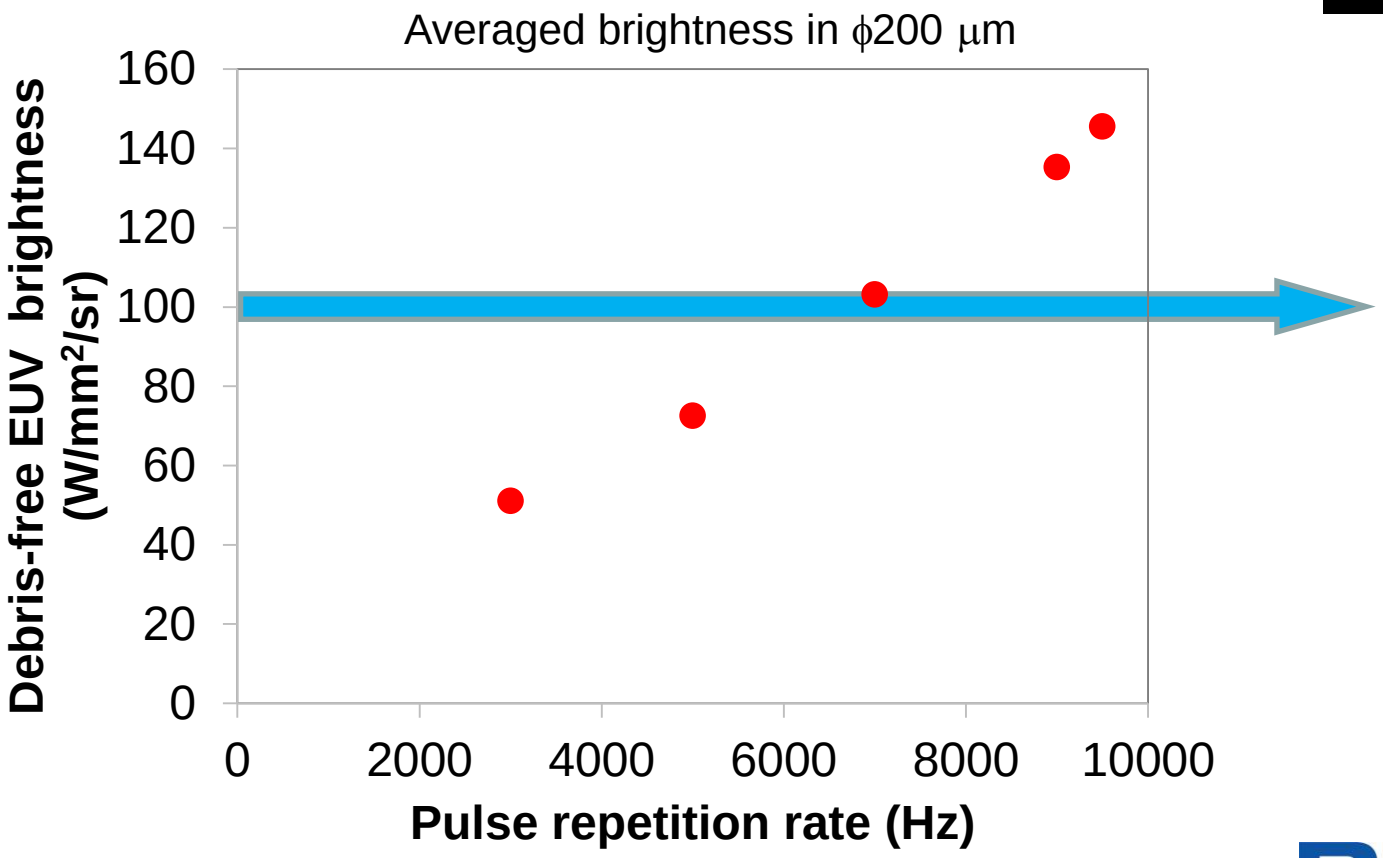
Brightness behind debris shield: 145 W/mm²/sr

Measured after debris shield as debris-free EUV photon

- ❑ Area-averaged brightness: 145 W/mm²/sr



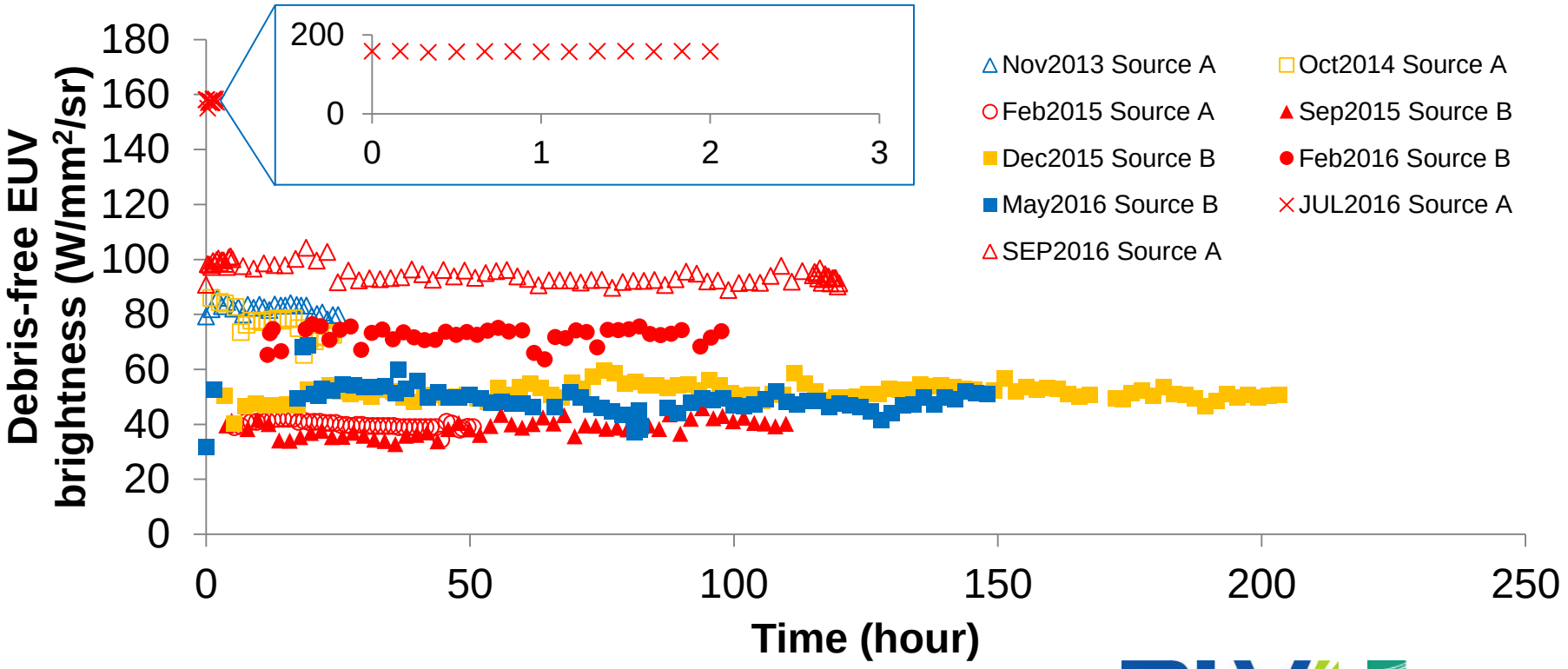
In-band EUV image
λ=13.5 nm, 2 % BW



This is what the industry wants.

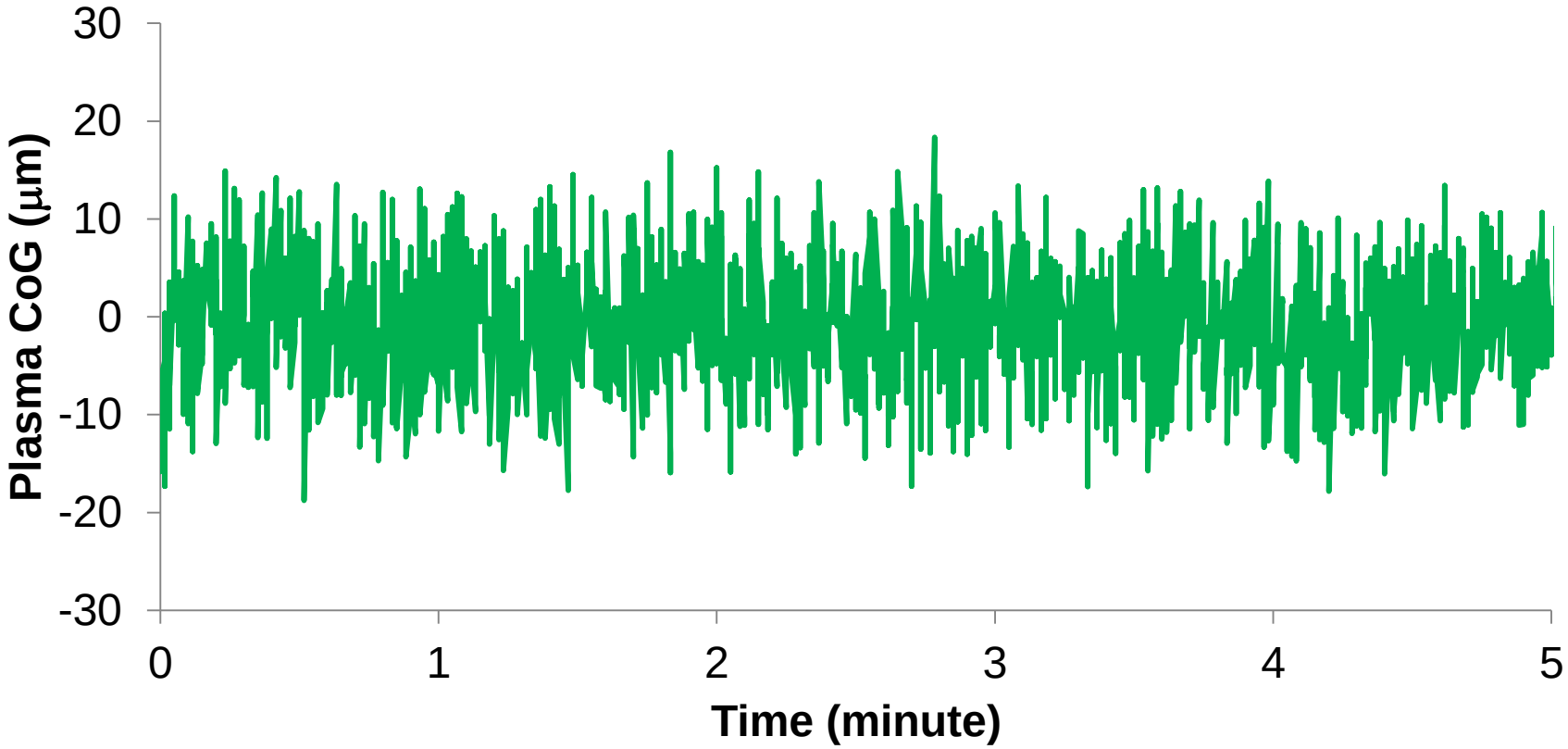
Reliability: tests ongoing

- Non-interrupted operations of up to 10 days were demonstrated, including
  - ✓ 100 W/mm²/sr for 5 days
  - ✓ 160 W/mm²/sr for 2 hours
- Tests continue to improve the system reliability and performance stability.



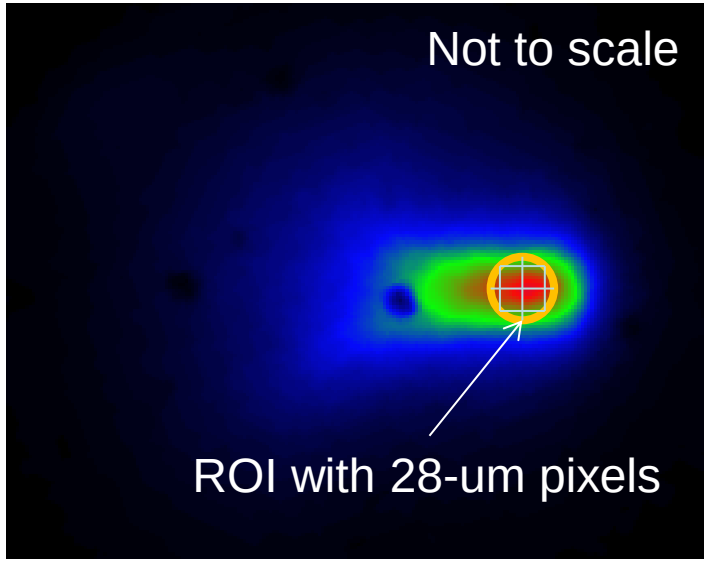
Position stability: ~6 μm

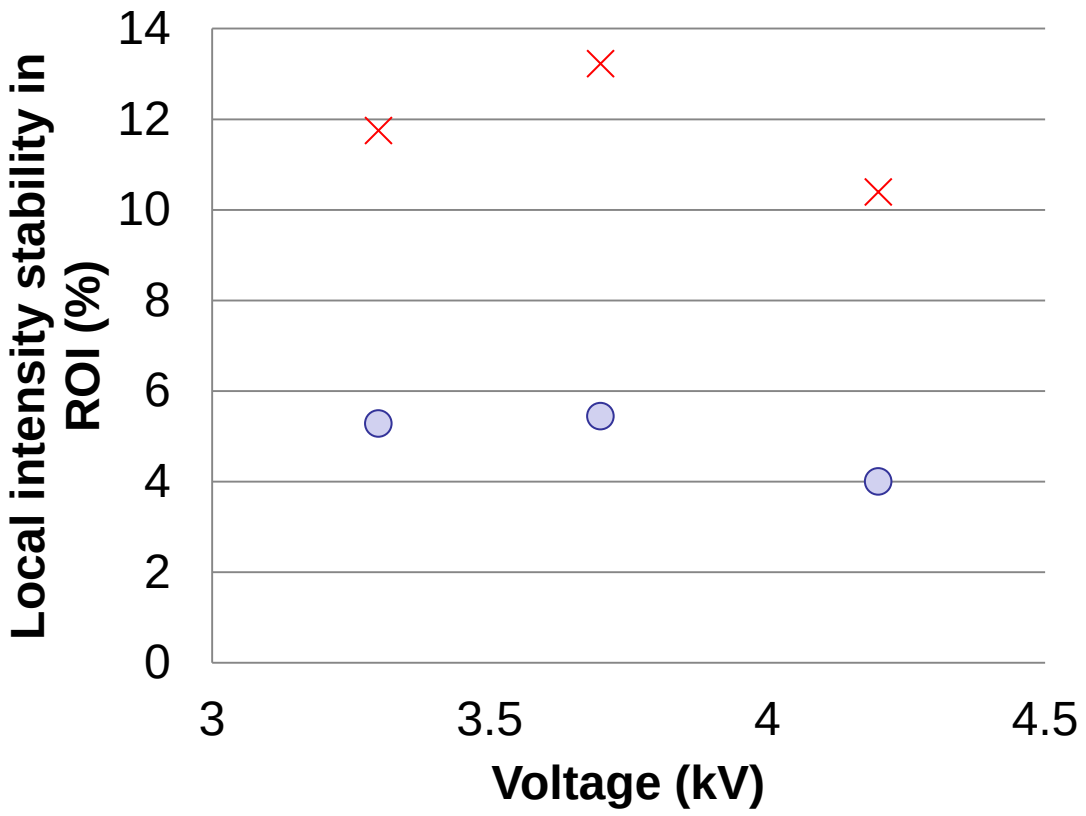
- Measured with camera placed on optical axis
  - Exposure time: 5 ms
- Standard deviation: 6.0~6.4 μm
  - <3 % of plasma size (200 μm)



Local intensity stability variation with voltage

- In general, the higher voltage provides better local intensity stability.
- Faster discharge might be reducing the influence of MHD instability.





Compact EUV/X-ray source

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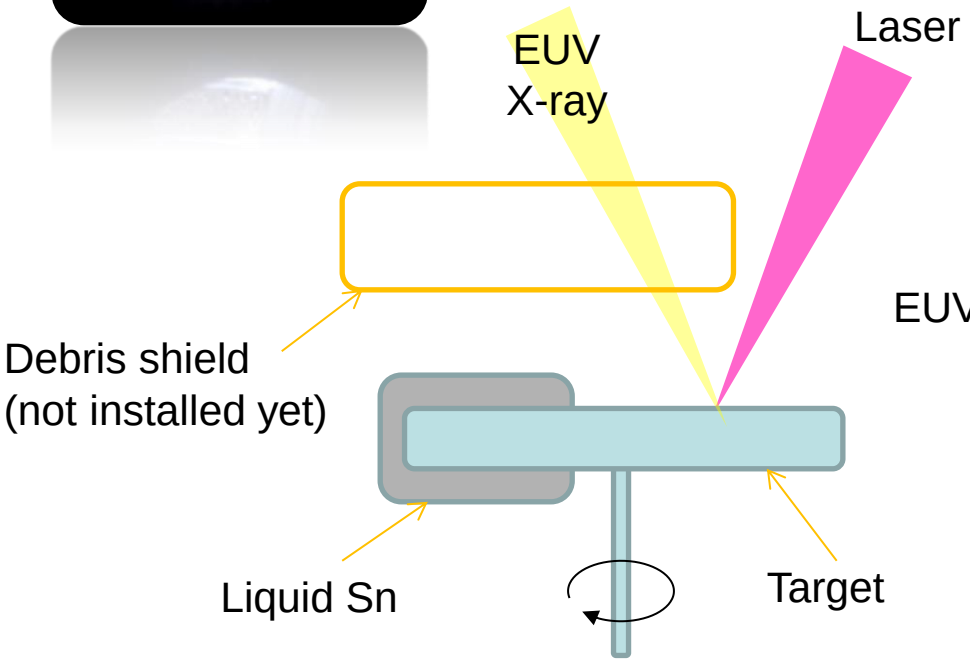
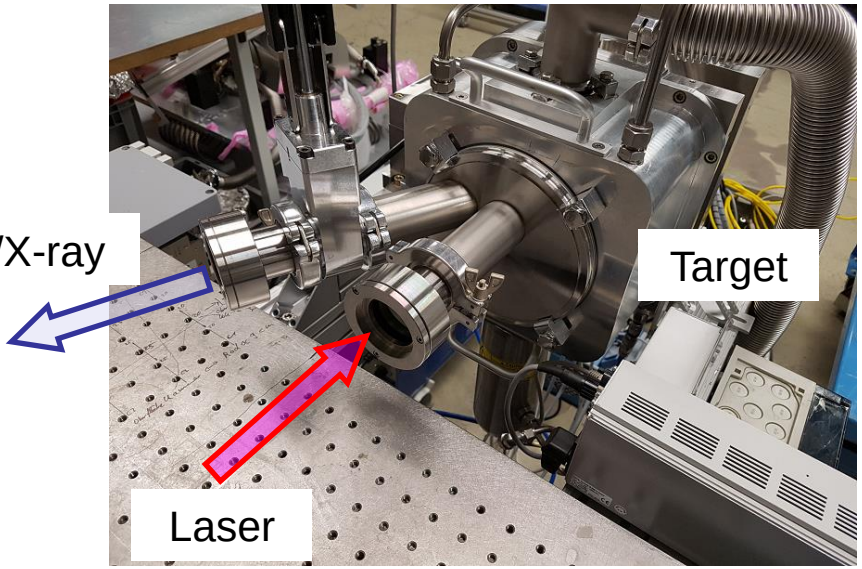
Proof-of-concept experimental setup

- Laser-driven source
- Low output power
- High output brightness
- Table-top size
- Continuous target supply





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LDP-LPP spectrum comparison

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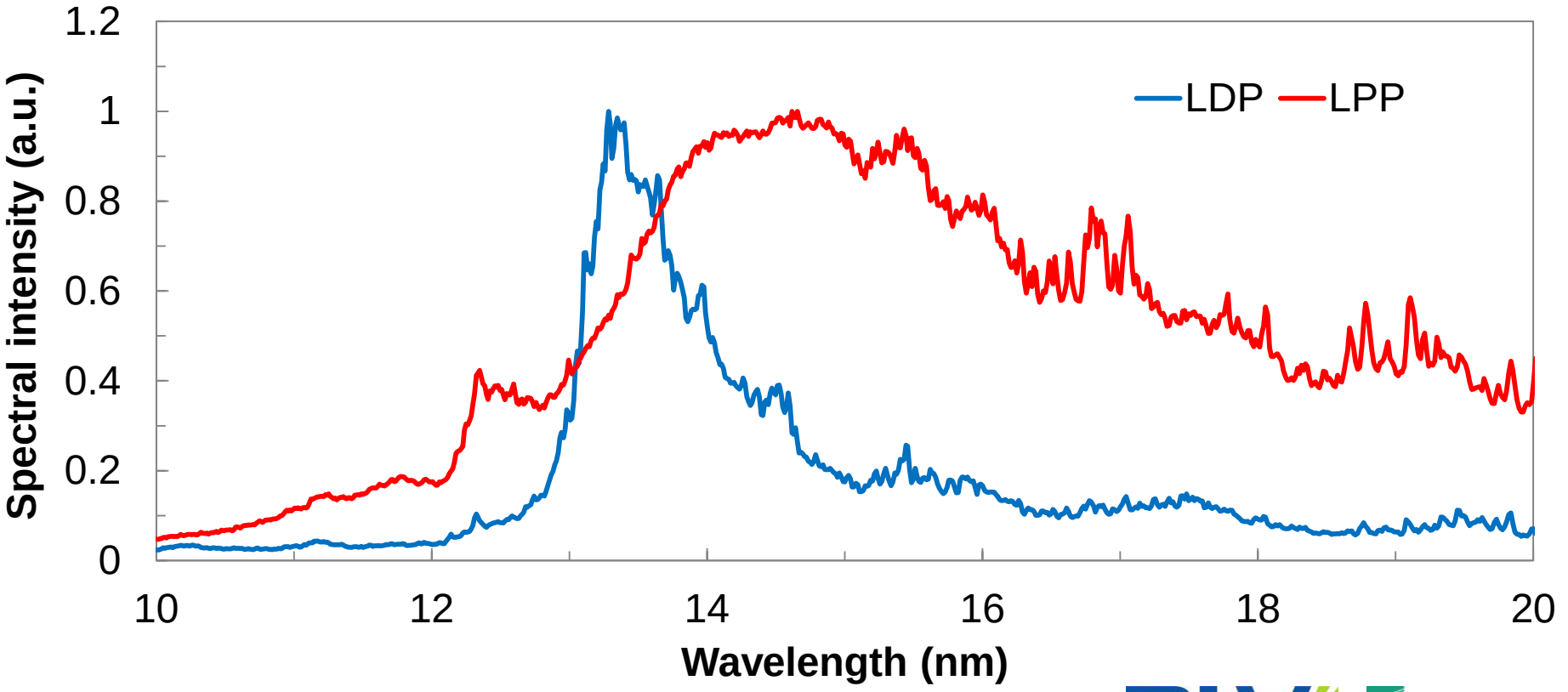
PoC exp 1

- LPP spectrum is much wider than that of LDP. LDP spectrum is narrower than that of LPP because of its low (suitable) ion density.
- Spectrum optimization by laser parameter adjustment might be possible.



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Compact source: brightness scaling

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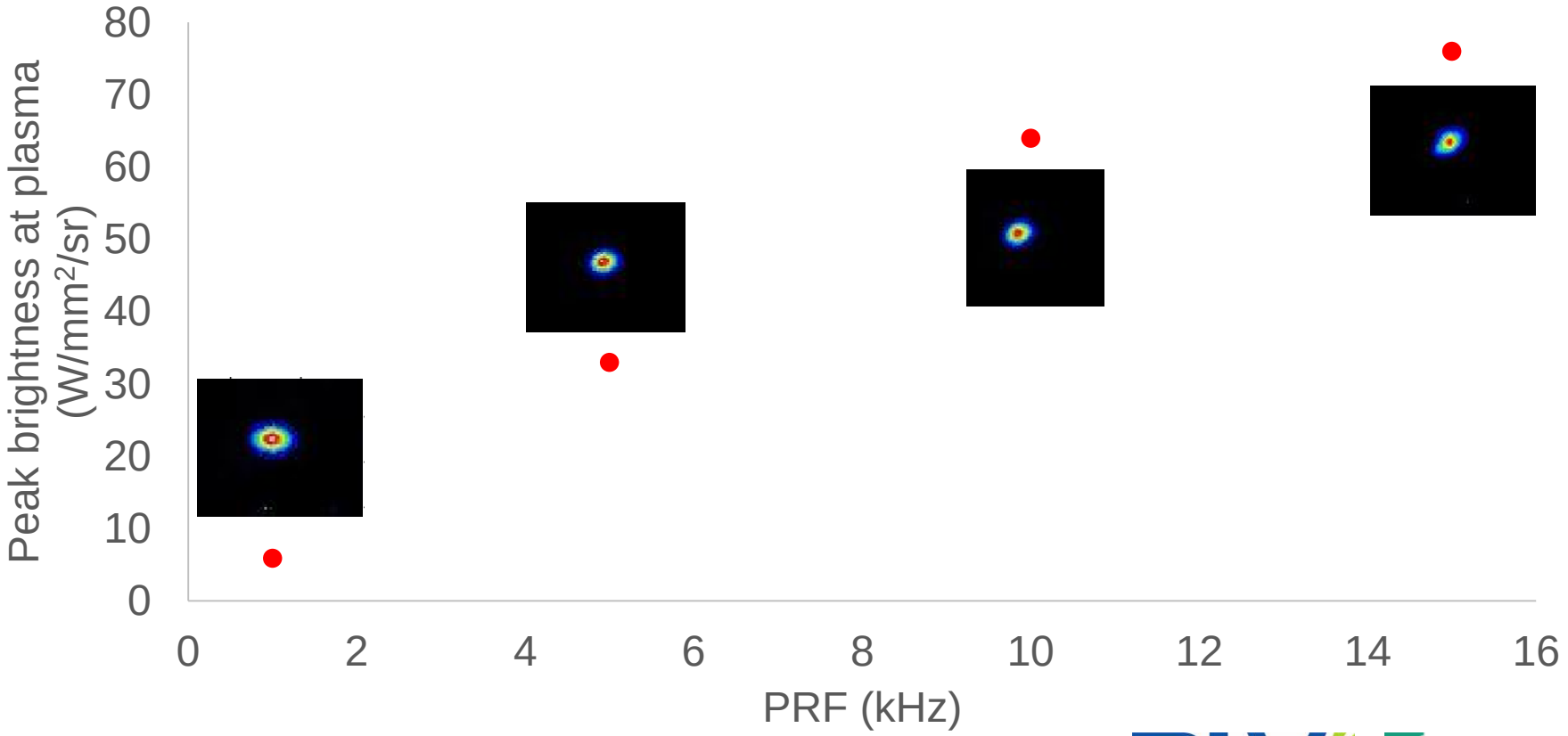
PoC exp 2

- Scalability up to 15 kHz was tested and 76 W/mm^2/sr was observed so far.
- CE improvement is planned by increasing laser intensity.
- Mid- and long-term stability will be evaluated at each frequency.



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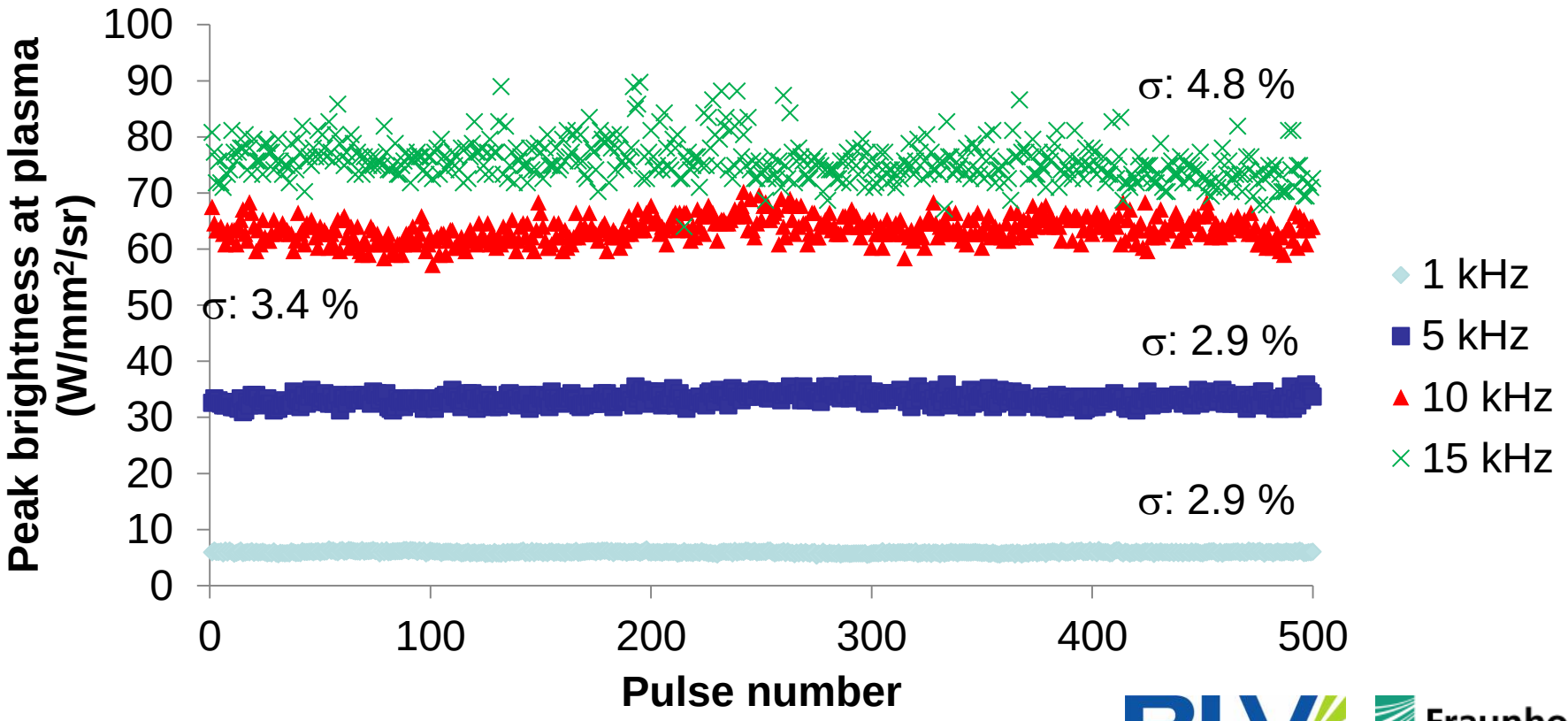
Compact source: brightness stability

PoC exp 2

- Short-term stability was confirmed to be good.
- Next step:
  - Study on mid- and long-term stability.

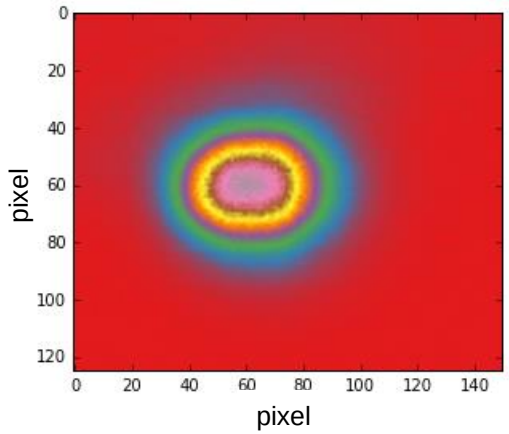


Compact source: plasma position stability

PoC exp 3

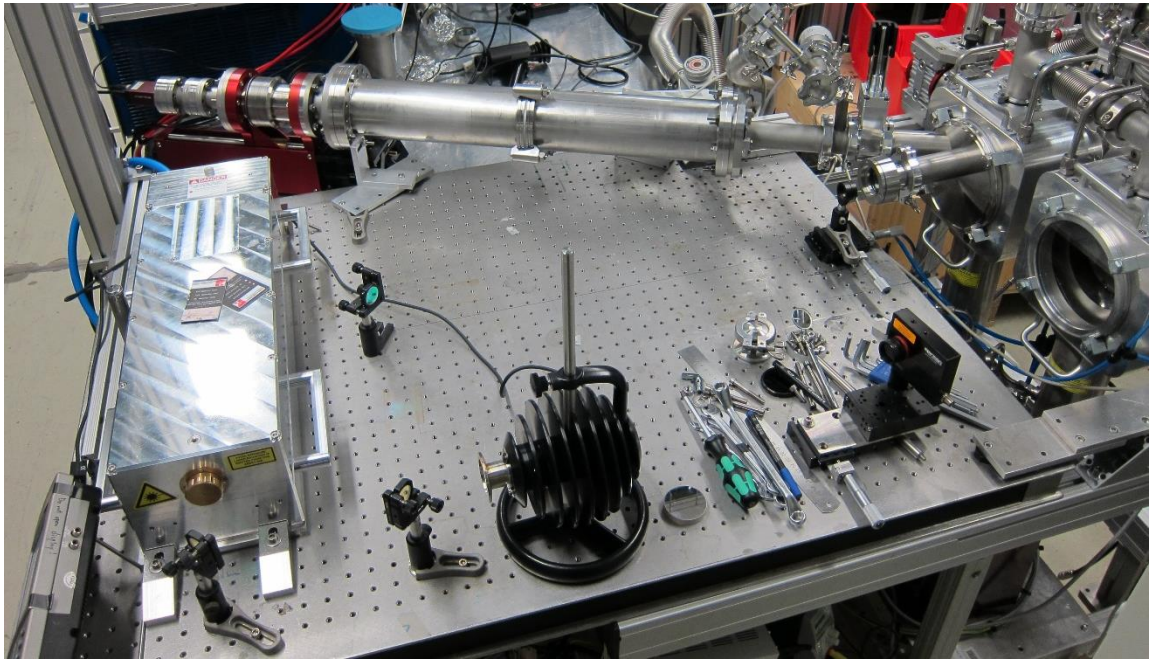
Laser

- Wavelength: 1,064 nm
- Pulse energy: 13 mJ
- Intensity: 2.6×10^{10} W/cm^2
- Frequency: 1 kHz



In-band EUV camera

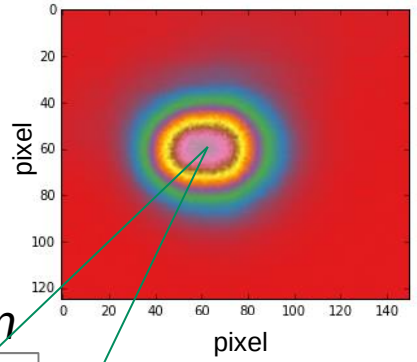
- Optics: Schwarzschild
- Magnification: 5.43
- CCD pixel size: 6.5 x 6.5 µm²
- Exposure time: 1 ms (single pulse imaging)

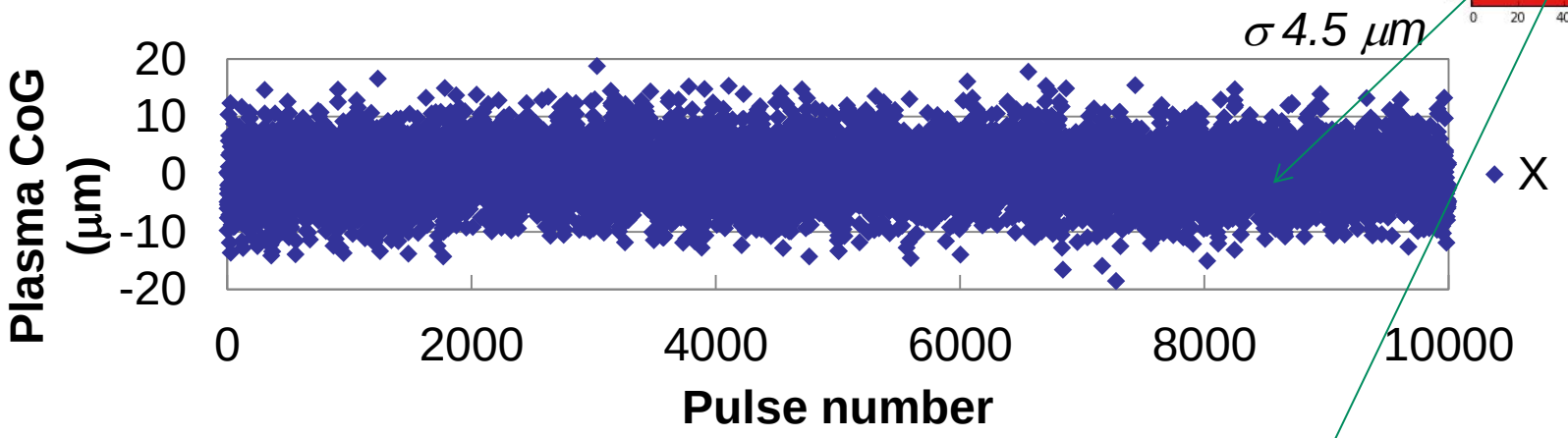


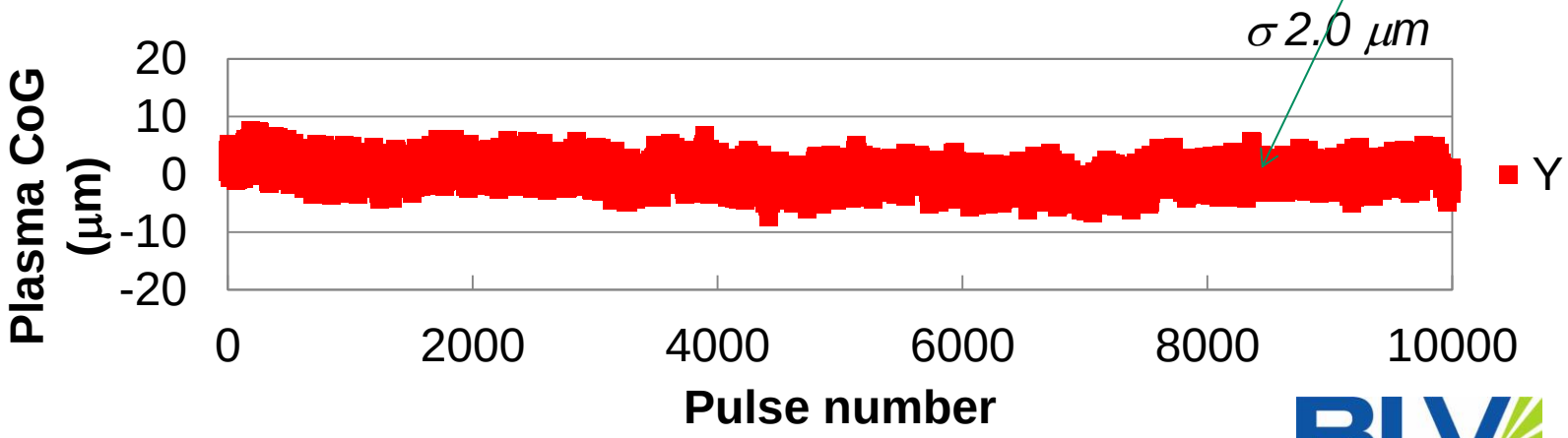
Compact source: plasma position stability

PoC exp 3

- Stability at 1 kHz based on 10,000 single-pulse images.
- CoG stability was 4.5 μm (X) and 2.0 μm (Y).







Summary

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Laser-assisted source

- ❑ Brightness of Sn-LDP source is sufficiently high for enabling EUV actinic mask inspections (ABI, API and AIMS).
- ❑ Position stability was approximately 6 μm.
- ❑ Local intensity stability was studied.

Laser-driven source

- ❑ Compact LPP source is being studied as EUV and X-ray sources.
- ❑ Sn-LPP PoC experiments showed the brightness of 76 W/mm^2/sr at 15 kHz.
- ❑ Short-time brightness stability was 3-5 % (pulse-to-pulse). Position stability was 2-5 μm (pulse-to-pulse).

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